Rapid Modeling, Assembly and Simulation in Design Optimization

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Abstract

A new capability for design is reviewed. This capability provides for rapid assembly of detail finite element models early in the design process where costs are most effectively impacted. This creates an engineering environment which enables comprehensive analysis and design optimization early in the design process. Graphical interactive computing makes it possible for the engineer to interact with the design while performing comprehensive design studies. This rapid assembly capability is enabled by the use of Interface Technology, to couple independently created models which can be archived and made accessible to the designer. Results are presented to demonstrate the capability.

1 INTRODUCTION

Today, design and production are being driven by revolutionizing forces. Technology is moving rapidly and competitive forces require new affordable products with increasing capabilities to come to market quickly and deliver lasting value at competitive cost. Products must be affordable, maintainable and safely disposable. Moreover, the birth of Integrated Product and Process Design attests to the belief that the design process must encompasses more than what has been traditional design; it must encompass manufacturing, maintenance and repair, initial and life cycle costs, and disposal.

It is well documented that product costs are set in the early conceptual phase of the design process. Generally, the models used for conceptual design consist of simplified rules (relative to those used in detail design) and formulas which have been embedded into complex spreadsheets. The spreadsheet entries are filled with formulas developed over many years of experience in that discipline. There exist severe limitations in this early design process as it cannot account for critical details which can become very costly items later in the design process. At some point in the design process, (usually at preliminary design), there is a change-over to more physics-based design methods such as finite elements. Because the preliminary models are physics-based rather than experience-based, they can be continuously refined with more detail added as the design process progresses. However, if available early in design, the critical detail in the finite element models could provide the data needed for better design decisions and avoidance of costly and time-consuming re-designs. Costs, design cycle time and risk could be reduced if more knowledge of the design were available. Thus, it is desirable to have a seamless design process in which analysis at any level of detail is possible. This can be done by bringing the finite element models up into the early part of the design process.

The difficulty with using the finite element method in early design is that is can be cumbersome, tedious and expensive. However, a new development referred to as interface technology[1-6] is enabling models to be created easily and quickly. This technology has many applications as indicated in figure 1. Also, rapid equation solvers coupled with the revolutionary changes in computer hardware and software engineering, are allowing finite elements to be utilized at the earliest phases of the design.

The purpose of this paper is to review the recent developments in interface technology, rapid assembly and related technologies, and their application to design. This will be accomplished by presenting an overview of validation cases and several complex application cases of interest to the design optimization community.

2 Interface Technology

A new NASA technology, called "Interface Technology" provides the means for assembly of diverse structural models[1]. This technology opens the door to expeditious modeling, by removing the constraint of grid point compatability between finite element regions while providing accurate predictive capability.

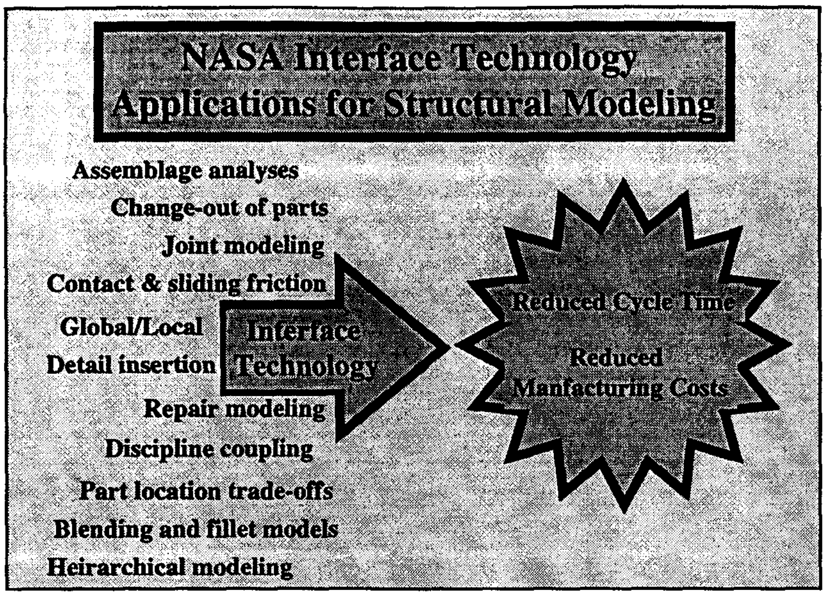


Figure 1 Applications of Interface Technology

Formulation[1]

It is not the purpose of this paper to re-derive the formulation upon which Interface Technology is based, rather, the formulation can be found in references 1 - 5 for linear applications and in reference 6 for nonlinear applications. The formulation is based on hybrid variational principles of mechanics where its hybrid character is derived from the variations of both displacement and traction conditions. After several years of experimentation, it was found that the hybrid character is necessary to achieve accurate displacement compatibility and traction continuity at the interface between two diverse (mismatched finite element meshes). This is necessary for the technology to be applicable for joining component models, since it is at the interface between the components that failures of the physical assembly occur and hence is where accuracy is most critical.

To provide for ease of use within finite element software codes, interface technology is used to derive a class of interface elements which operate like other finite elements, but which have no material properties, stiffness or mass. The interface elements can be thought of as "glue" which joins FEM models together. In this way, it provides a transitioning role between meshes, without having a traditional transitioning mesh as depicted in figure 2.

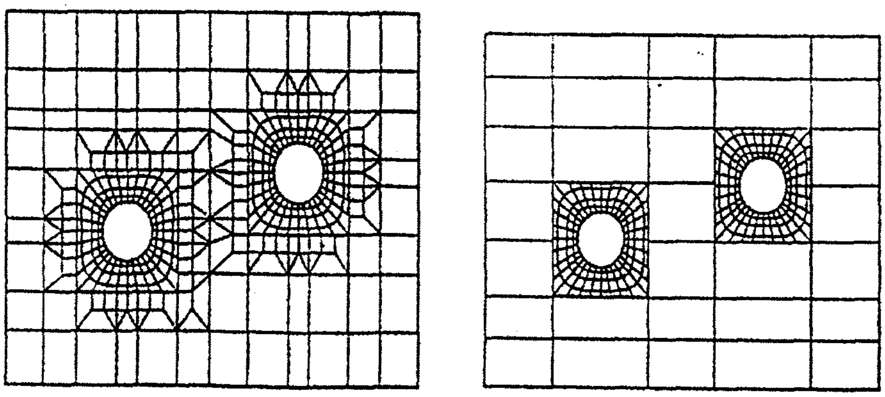
[1] The formulation of interface technology is also applicable to the synthesis of non-FEM models. However, its immediate application is in FEM and for this reason, research in this area has been pursued most vigorously.

Traditional finite element transitioning mesh between fine near-field meshes in the neighborhood of stress risers and coarse far-field meshes is not only tedious to create, but leads to distorted elements whose accuracy is questionable. Hence, interface elements alone do not improve the quality of finite element results obtained by a particular model, but rather improve the efficiency of the modeling and make effective use of existing finite elements.

3 Applications of Interface Technology

Global/Local Modeling

As shown in figure 2, global/local modeling typically involves the use of a fine mesh near the localized high stress region of the model and a coarse mesh in the global region of the model. The two meshes are typically connected by a transition mesh region. The transition mesh, whether done manually or automatically invariably leads to distorted elements when the transitioning constraint of nodal compatibility is enforced. It is well known that for most classes of elements, distorted elements, (considerably non-square plate and shell elements or non-cubic and non-tetrahedral elements), give poor results in their vicinity.



(a) With Transition Modeling (b) With Interface Technology

Figure 2. Global Local Modeling Around Cutouts

As shown in figure 2, interface technology completely eliminates the need for transition mesh by removing the nodal compatibility constraint. The result is no distorted elements and hence more accuracy. Moreover, if the transition mesh is created manually, or partly manually (such as to fix automatically generated meshes), tedious time-consuming transition mesh development is eliminated.

Insertion and Change-Out of Features

Insertion of detail local models into existing models may be accomplished with relative ease; thereby allowing design engineers to add local features to baseline design models or to change-out features. These features may take the form of cutouts, attachments, repaired structure, design modifications or they may be inserted cracks and fractures required for determining damage tolerance.

Figure 3 illustrates the change-out of features utilizing different cutout shapes and sizes in a flat plate under tensile loading. Elliptic cutouts with major axes oriented both longitudinally and transversely, and of different sizes are shown. In all cases the baseline plate model remains the same.

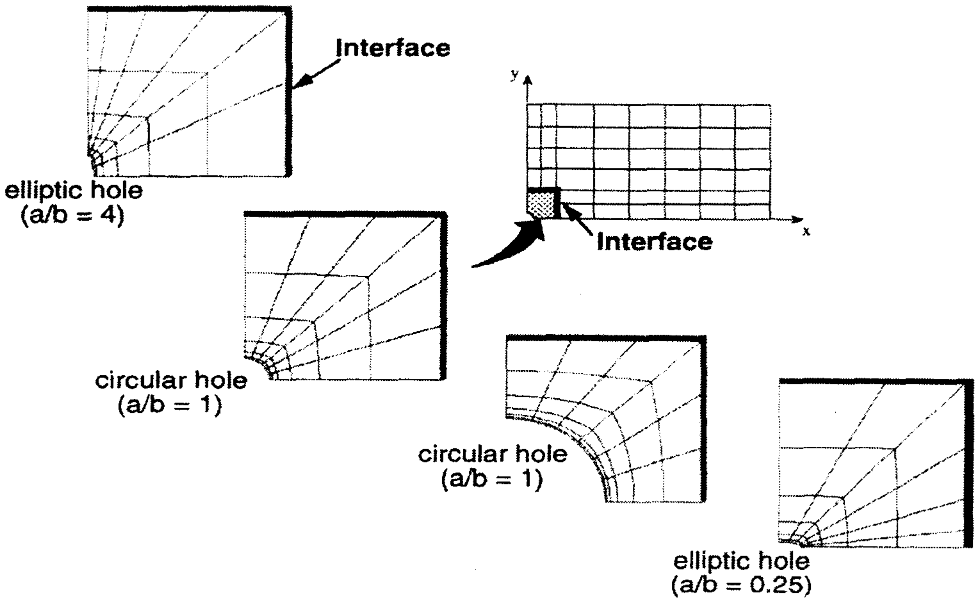


Figure 3. Change-out of cutout shapes and sizes in rectangular plate, one quarter plate shown

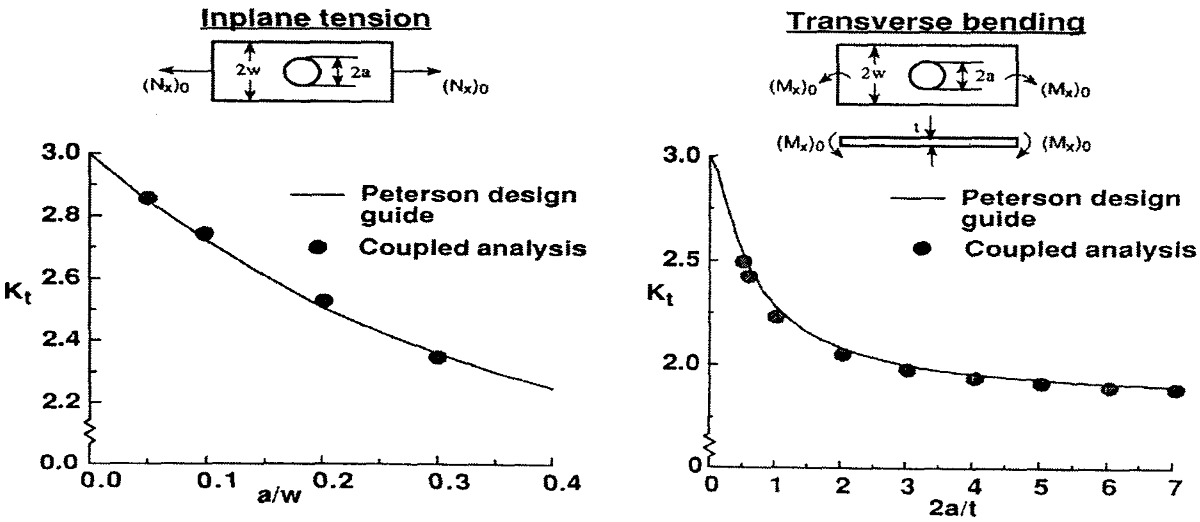


Figure 4 Stress intensity factors for rectangular plates with circular cutout using interface technology to insert local hole modeling

Figures 4 and 5 provide results derived from a change-out study using interface technology. Each data point on the curves displayed in these figures represents an analysis using a different size and/or shape cutout model which is interfaced to the same baseline model. Comparisons with results from the literature are provided in the figures. Clearly, the interface elements provide a high-fidelity joining of the baseline and inserted meshes.

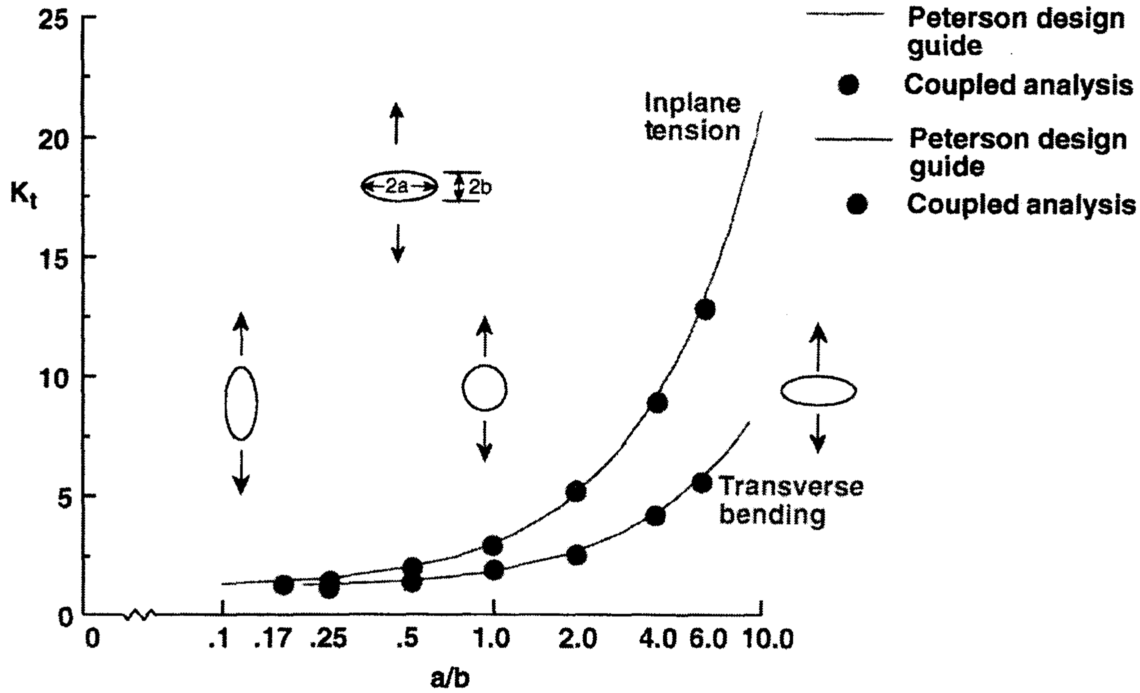


Figure 5. Stress intensity factors for elliptical cutouts or various shapes in rectangular plates utilizing interface technology to insert local cutout models

Nonlinear Applications

As a classical example of nonlinear modeling, an isotropic cylindrical panel which is subjected to a concentrated load at its center and which is hinged on its two straight edges and free on its two curved edges is shown in Figure 8. The panel material properties are 3.10275 kN/mm^2 (450 ksi) for the Young's modulus and 0.3 for the Poisson's ratio.

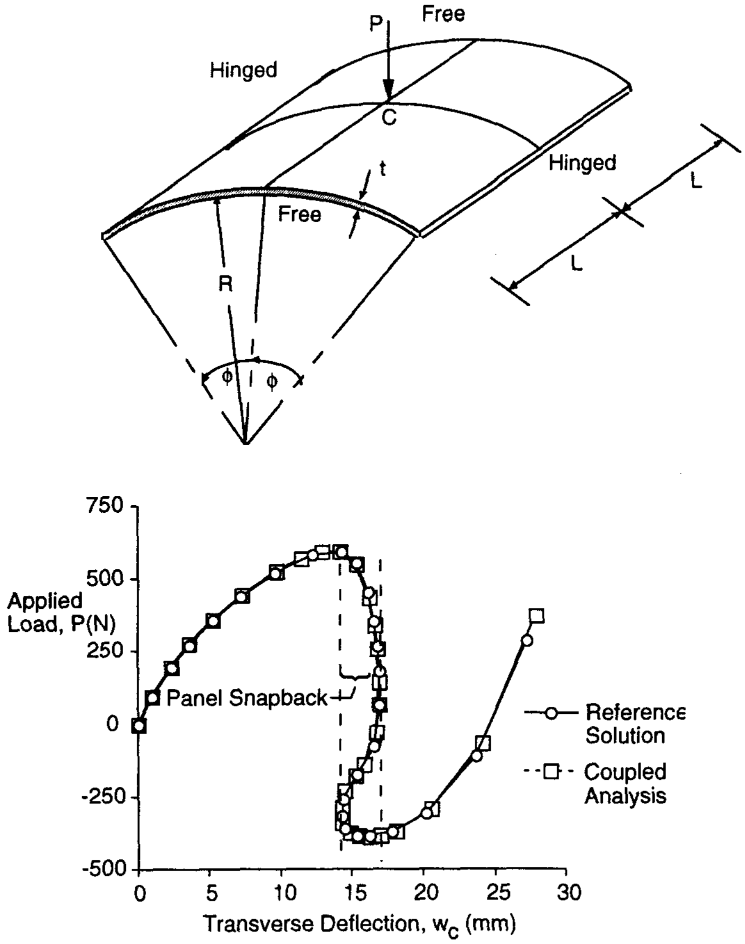


Figure 6. Nonlinear snap through of shallow cylinder

The panel radius, R, is 2540 mm. (100 in.); the panel half-length, L, is 254 mm. (10 in.); and the half-opening angle, j, is 0.1 radians. Two panel thicknesses, t, were considered: a thickness of 12.7 mm. (0.5 in.) and a thickness of 6.35 mm. (0.25 in.), yielding radius-to-thickness ratios, R/t, of 400 and 200, respectively. Both the thick and thin panels exhibit a limit point and snap-through behavior as the load is increased, and the panels collapse into an inverted configuration. In addition, the thin panel exhibits a snap-back behavior as shown. The interface is located along longitudinal line of symmetry.

Meshing of independent regions and assembly modeling

Finite element modeling is a tedious job even with the use of the most modern automatic meshing software. On the other hand, assembly is a much easier process and allows the efficient re-use of models which appear in many different designs. For example, a hat stiffener differs little from one application to another. Yet, in every application case using a hat stiffener, it is typically remeshed in such a way that the grid points on the stiffener match those on the skin. Interface technology eliminates this requirement.

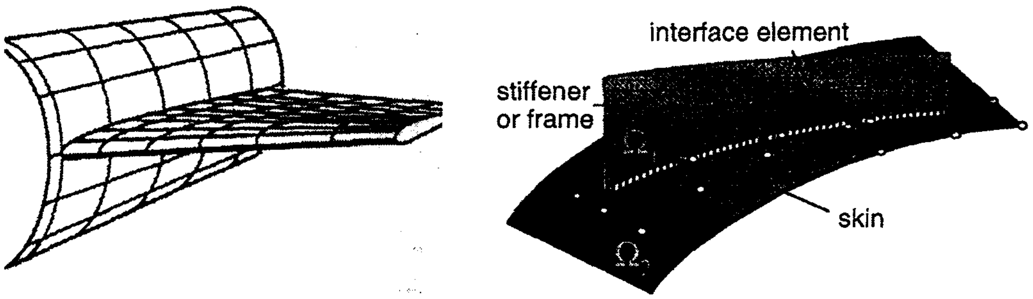


Figure 7 Assembled models having incompatible meshes

Thus, a stiffener can be resized in any of its dimensions and connected to a skin without concern for mesh compatibility. This capability enables the creation of component library models which may be accessed and shared throughout a company or between contractor and sub-contractor or contractor and supplier. Each organization or contractor participating in a project could be responsible for the model of their component Each organization or contractor participating in a project could be responsible for their model of their component independently of another organization's component model. This is shown schematically in figure 7.

A Prototype Graphical User Interface (GUI) is now being developed to allow engineers to access such libraries using mouse operations of click, drag and drop. This should greatly reduce engineering time and allow for much more comprehensive design studies. Such a system is depicted in figure 8. Solid models of components and associated finite element models are stored in the library. The library contents are displayed on the left hand side of the screen. Any component may be selected. The component is dragged from the library with a mouse and then dropped into the main portion of the screen. Associated with the component is a solid model representation as well as the finite element model and a menu allows the user to switch back and forth between these representations. The system allows the components to be translated, rotated and sized. Since the components are represented by intelligent models, the models know their connection points with one another and snap together when brought into vicinity with one another. Interface elements are automatically created to provide accurate joining. In this way, complex structural finite element and solid models are quickly assembled from building block models.

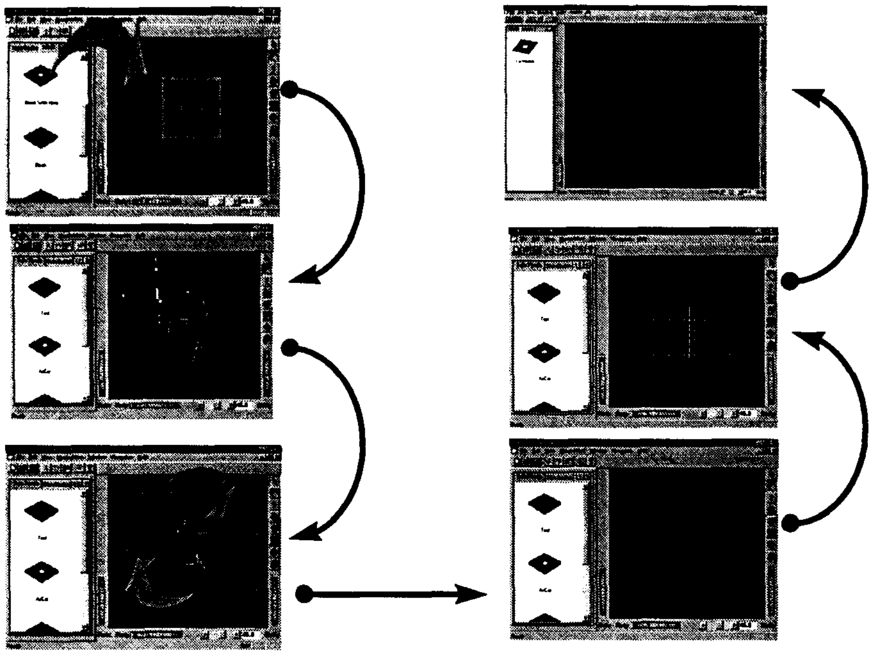


Figure 8. Assembly of basic building block solid and finite element models using Graphical User Interface

4 Concluding Remarks

Rapid assembly of detail finite element models creates an engineering environment which enables comprehensive analysis and design optimization early in the design process. Graphical interactive computing makes it possible for the engineer to interact with the design while performing comprehensive design studies. This rapid assembly capability is enabled by the use of Interface Technology, to couple independently created models which can be archived and made accessible to the designer. As new assemblies are created, the models for these can also be archived so that over a period of time, extensive library classes are available for design and work done on previous designs can be reused effectively and efficiently.

5 References

1. Housner, J. M. and Aminpour, M. A. Multiple Methods Integration for Structural Mechanics Analysis and Design. Proceedings of the Second Advanced Composites Technology Conference, Seattle, Washington, November 1991.

2. Aminpour, M. A., Ransom, J. B., and McCleary, S. L., "Coupled Analysis of Independently Modeled Finite Element Subdomains," AIAA Paper Number 92-2235, 1992.

3. Ransom, J. B., McCleary, S. L., and Aminpour, M. A., "A New Interface Element for Connecting Independently Modeled Substructures," AIAA Paper Number 93-1503, 1993.

4. Aminpour, M. A., Krishnamurthy, T. McCleary, S. L., and Baddourah, M. A., "Application of a New Interface Element to the Global/Local Analysis of a Boeing Composite Crown Panel," *Fourth NASA/DoD Advanced Composites Technology Conference*, June 7-11, Salt Lake City, UT, NASA CP-3229, compiled by J. G. Davis, Jr., J. E. Gardner, and M. B. Dow, Volume I, Part 2, 1993, pp. 773-788.

5. Schiermeier, J. E., Housner, J. M., Ransom, J. B., Aminpour, M. A., and Stroud, W. J., "The Application of Interface Elements to Dissimilar Meshes in Global/Local Analysis," Proceedings of the 1996 MSC World Users' Conference, Newport Beach, CA, June 3-7, 1992.

6. Ransom, J. B. Interface technology for Geometrically Nonlinear Analysis of Multiple Connected Subdomains. Proceedings of the 38th AIAA Structures, Structural Dynamics and Materials Conference. AIAA Paper Number 97-1298. April 1997.